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THIRD SERIES—VOLUME LV—SECTION III
JUNE, 1961

OTTAWA
THE ROYAL SOCIETY OF CANADA
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SECTION III

PRESIDENTIAL ADDRESS

The Rôle of Star Clusters in our Understanding of the Galaxy

HELEN S. HOGG, F.R.S.C.

STARS are like people—they are fond of congregating in groups. From an astronomer's viewpoint there is a great advantage in having objects in groups. We can compare the relative brightness of the stars in a group, knowing that they are all at almost the same distance from us. We can compare them spectroscopically for abundance of chemical elements, assuming that they must have been formed from the same material. And by assuming also that they were formed at the same time, we can trace the evolutionary paths of stars of different masses.

We shall outline here some of the ways in which groups of stars have contributed to our knowledge of our own Milky Way system—our galaxy. In addition, some of the unsolved problems they have raised will be discussed.

There are three principal types of star clusters; globular clusters, galactic clusters, and associations. The associations are sparse groups of hot blue stars (types O or early B). More than fifty are known. They are relative newcomers and lack the years of observational study which have been given to the other types of star clusters. Therefore, this discussion will be confined to globular and galactic clusters.

Let us first consider globular clusters and the knowledge they bring to us of our galaxy. Globular clusters are systems of thousands to hundreds of thousands of stars in a spherical form, sometimes slightly oblate, in what must be rotational symmetry, though their great distances of tens of thousands of light years have so far made it impossible actually to observe the rotation. In and around our own galaxy, 120 are known. In the sky most of them subtend small angular diameters of a few minutes of arc. This means that their great light power is concentrated in a small area of the sky. Consequently they can be seen to the greatest distances of any of the objects belonging to our galactic system. In the early nineteenth century Sir William Herschel drew attention to the remarkable distribution of these objects, with a strong concentration towards the Milky Way fields in Sagittarius, but scattered all over the sky. In 1917 Harlow Shapley

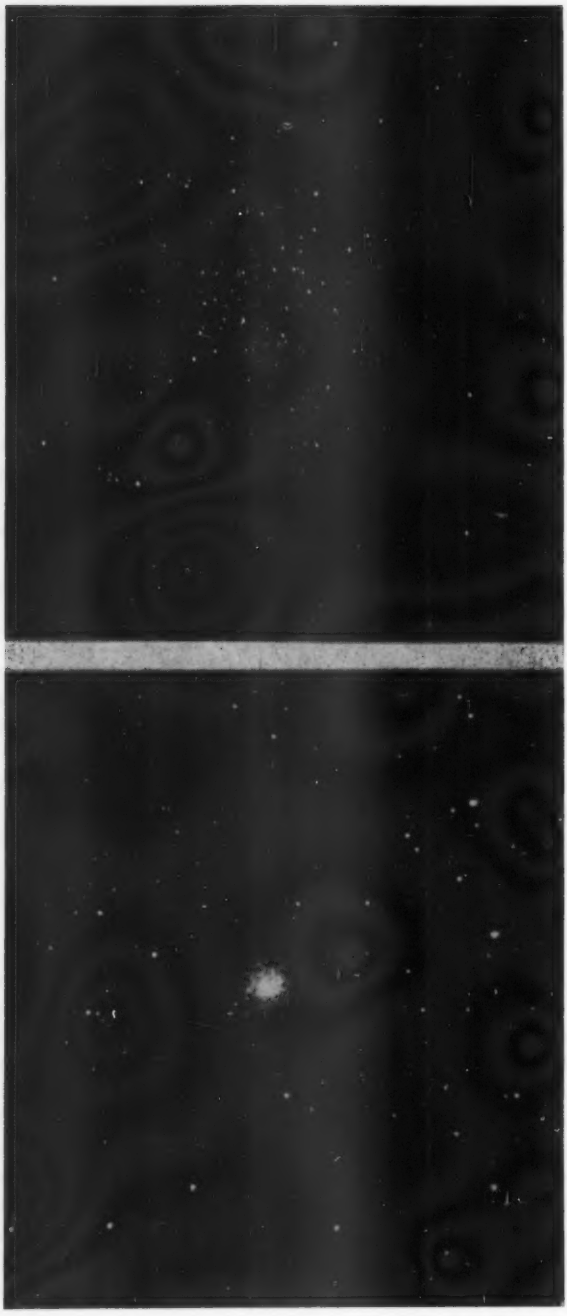

FIGURE 1. Globular clusters photographed with the 74-inch reflector of the David Dunlap Observatory. The upper is a loose globular cluster, NGC 5466, while the lower, NGC 6356, is a more concentrated type.

used this distribution to postulate that the central mass of our galaxy is in the direction of Sagittarius. The current estimate of the distance is from twenty-five to thirty thousand light years. Photographs by Walter Baade with the 200-inch reflector have resolved some of the stars in the nucleus. The over-all diameter of our galaxy is from eighty to one hundred thousand light years, and the distances of the globular clusters are significant in obtaining this. In the up-and-down direction there is a distance of over one hundred thousand light years perpendicular to the central plane between several globular clusters.

The study of the individual stars in a globular cluster has proved of great significance. The colour-magnitude diagram for the stars in a globular cluster is very different from that for the stars in the neighbourhood of our sun. The stars in globular clusters are good representatives of Baade's Type II population: old stars, found also in the galactic nucleus and halo. The brightest stars in globular clusters are yellow giants. When colours are plotted against either apparent or absolute magnitude (because the relation between the two is linear for the stars in a given cluster) the diagram shows a horizontal branch and then a strong downward slope to the right. This is the main sequence of stars which are burning the hydrogen in their cores to provide their outpouring of energy. The shape of the colour-magnitude diagram, in particular the point where it turns off from the main sequence, may be used to estimate the age of the cluster. One of the most complete colour-magnitude diagrams to date is that obtained for the globular cluster Messier 3, by Allan Sandage (1) with the 200-inch telescope. This work was accompanied by star counts of almost 50,000 stars in this cluster. However, the faintest stars in any globular cluster have not yet been photographed. A telescope on the moon will be of great advantage here.

Many of the individual stars in globular clusters are variables, that is, they vary in light output. In fact, essentially 10 per cent of all the variables known at present in our galaxy are found in the globular clusters. In these clusters the short period RR Lyrae variables predominate, constituting 90 per cent of the variables in globular clusters. These are the stars with periods less than one day, designated as cluster type variables when they were noted by S. I. Bailey (1) of Harvard sixty years ago. These variables occupy a particular place on the colour-magnitude diagram, as first pointed out by Martin Schwarzschild (1) in 1940. This region of the diagram, known as the RR Lyrae gap, seems to represent a period of instability in the life history of a star. The RR Lyrae variables have for years been assumed to have an absolute mean magnitude of 0.0, the same for all periods. However, work of the last several years raises real doubt as to the truth of this value, or its constancy. In some clusters it may be fainter by half a magnitude or more. This can have a substantial effect on the computation of globular cluster distances, and a revision of these for some clusters may be in order.

The field of variables in globular clusters should be of interest to Cana-

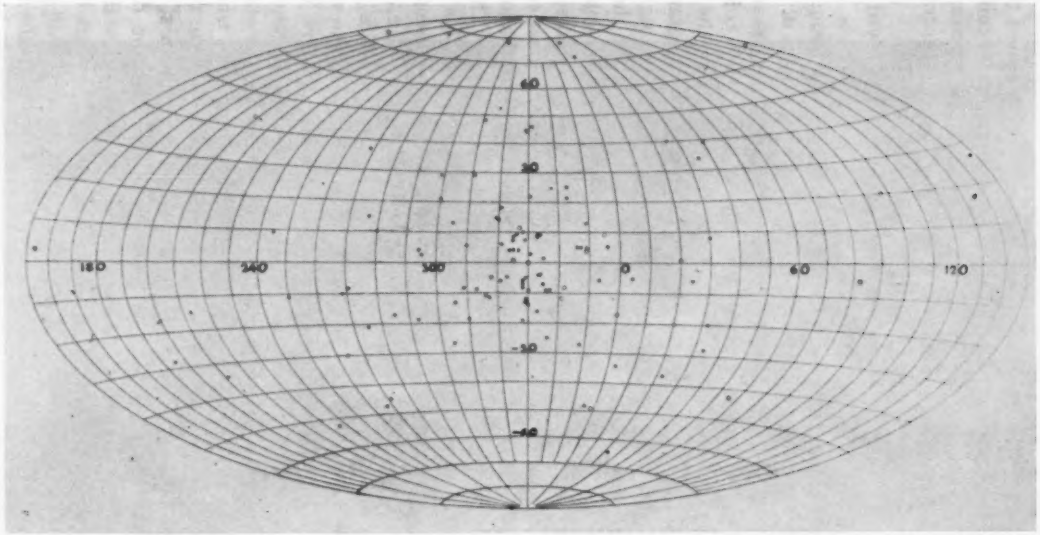

FIGURE 2. Distribution of globular star clusters in galactic co-ordinates on an Aitoff projection. The central horizontal line represents the central plane of the Milky Way. Abscissae are galactic longitudes, ordinates, galactic latitudes.

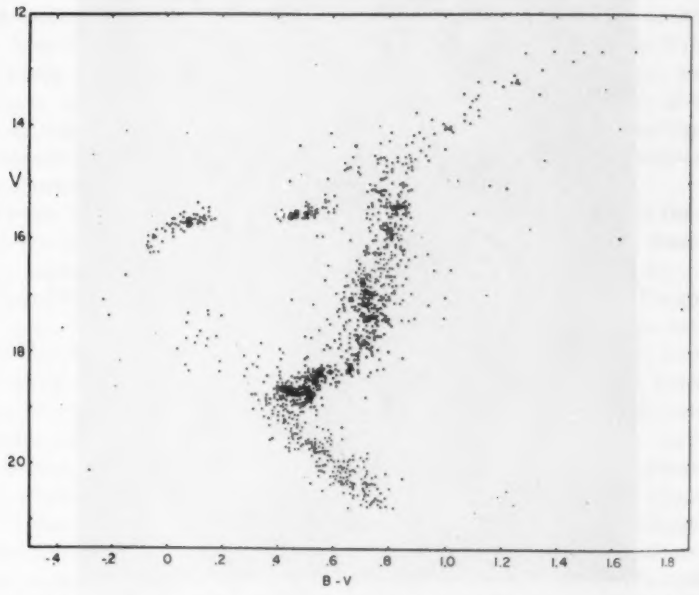

FIGURE 3. The colour-magnitude diagram of the globular cluster Messier 3, by H. L. Johnson and A. R. Sandage, Astrophys. J., *124* (1956), 379.

dians because an observational programme, begun with the 73-inch reflector of the Dominion Astrophysical Observatory in Victoria thirty years ago, and carried on for twenty-six consecutive years with the David Dunlap 74-inch reflector has yielded a substantial percentage of the available data on new variables discovered, and periods determined. There are now 1612 variables known, from seventy-nine clusters searched. Periods have been determined for 1058 stars in forty-five clusters. This is an increase of almost 200 variables and over 200 in number of periods from the last catalogue published by the writer in 1955 (1).

The variables which are non-RR Lyrae stars, that is, with periods over one day, are an interesting assortment. Besides giving us a clue as to the class of variable which belongs with Type II stellar population, they also serve as distance indicators for the clusters through the period-luminosity relation for Cepheid variables. There are fifteen W Virginis stars (known as Type II Cepheids) with periods over ten days, and seventeen Cepheids with periods less than ten days. There are forty irregular or semi-regular variables and four RV Tauri stars (that interesting type which alternates deep and shallow minima in the light curve). We have followed several of these with the 19-inch telescope at the David Dunlap Observatory every night for many weeks, in order to untangle the intricacies of their light changes. There are a few Mira-type variables, the most notable being the

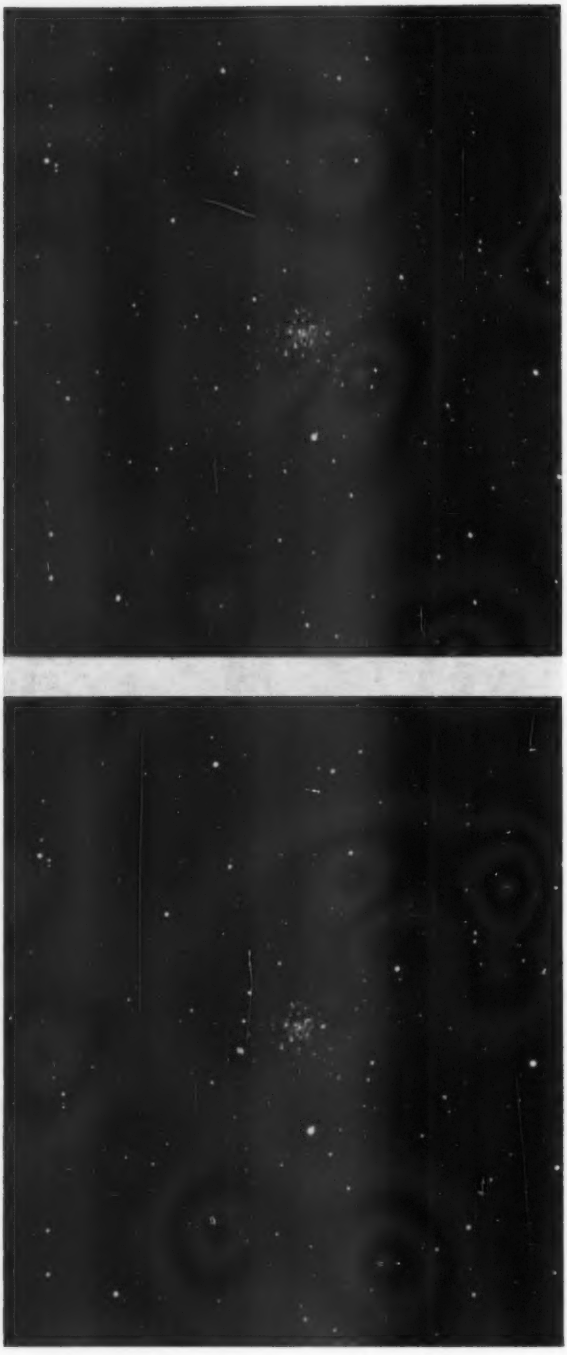

FIGURE 4. Two photographs of the globular cluster Messier 56 taken with the 74-inch David Dunlap reflector, showing change in magnitude of an RV Tauri-type variable. The variable is the brightest star just right of the centre of the cluster. On the lower photograph, taken July 5, 1946, the star is magnitude 13.0, near maximum, while on the upper, taken June 17, 1952, the variable is near minimum at 14.2.

three associated with the remarkable cluster 47 Tucanae in the southern sky. Spectroscopic work on the slow variables by Joy at Mount Wilson, and Feast and Thackeray at Radcliffe Observatory, South Africa, shows them to have characteristics similar to those of variables in the general field of the galactic system. Halton Arp (1) postulates that the type of variable present in a cluster depends on the placement of the giant sequences in the colour-magnitude diagram of the cluster.

Studies, especially by N. U. Mayall (1), of the radial velocities of the globular clusters (that is, speed of approach or recession) show that these are much higher than for single stars, ranging from −360 km/sec to +291 km/sec. This is a reflection of the sun's motion in its course around the galactic centre. However, after subtracting the usual allowance for solar motion of 260 km/sec towards Cygnus, and 20 km/sec towards Hercules, there is still a residual, indicating a real difference of 80 to 100 km/sec between the solar motion with respect to the galactic centre and to the system of globular clusters. The logical explanation of this discrepancy is that the whole system of globular clusters partakes in the general galactic rotation.

The integrated spectra of globular clusters, obtained both for study of the aforementioned velocities and for their own sake, are an intriguing problem. Globular clusters are certainly among the oldest systems we know, and this great age applies to their individual stars as well. According to present theories of stellar evolution, this means that the stars in a globular cluster formed out of the simplest kind of interstellar material, rich in the elements of low atomic number, and very poor in the metals and heavier elements. It has been known for years that globular clusters exhibit metal weakness, as shown by weak cyanogen absorption, and an ultraviolet excess in colour due to the absence of the blanketing effect of metallic line absorption in the blue region. So far, well and good. The facts and theory fit neatly. But in recent years, W. W. Morgan of Yerkes (2) has found a number of globular clusters, NGC 6356, 6528, and 6553 in which the metallic line strength is great, almost approaching that of our sun, which is presumed to be a third-generation star (that is, the material forming our sun is now supposed to have been spewed out twice over from earlier stars, in whose hot interiors the heavier elements identified in the sun were built up). This is one of the more important problems of globular clusters. Were they not formed all together in the early stages of our galaxy? Or does the composition of the interstellar clouds actually vary with their location in the galaxy—say, for example, with proximity to supernovae explosions—so that metal content is not as reliable an indicator of the age of the interstellar material forming the star as we believed it to be a few years ago?

Another unsolved problem of the globular clusters pertains to those which are intergalactic. Of the 120 clusters, about half a dozen are so far away that we can hardly claim them for our galaxy. We know that many of the external galaxies have large numbers of globular clusters—Messier 87, a giant EO galaxy in Virgo is supposed to have a thousand. But these

intergalactic clusters do not belong very obviously to any other galaxy. The first intergalactic cluster to be noticed was NGC 2419. Dr. Walter Baade of Mount Wilson showed its distance to be 175,000 light years away—well beyond even the most optimistic limits of size of our galaxy. The cluster was given a catchy name, "the intergalactic tramp," and the matter was left at that. However, the photographs taken with the 48-inch Schmidt for the National Geographic–Palomar sky survey added several more clusters in this category; the distances of some of these are as great as four hundred thousand light years. These objects are so faint and difficult that no velocity studies have yet been done on them. Do these clusters have any relation at all to our galaxy? This question certainly raises the important problem, on which relatively little work has so far been done, as to just what is in the space between the galaxies. Is intergalactic space empty? Are there any clouds of hydrogen, for example? Are there stars in it? The discovery of globular clusters in what was considered to be empty space stresses the importance of this problem. And the presence of interstellar dust in unexpected places has recently been emphasized by the work of Morton Roberts (3), which shows that the controversial wisps of dark nebulosity appearing in globular clusters must actually be in the clusters themselves.

The proof that there are absorbing clouds of material scattered through our own galaxy came from a study of the other type of star cluster, the galactic clusters. Galactic clusters, with linear diameters up to fifty light years, are systems of tens or hundreds of stars, strung around the heavens close to the central plane of the Milky Way. Only a few of the nearest appear projected into high galactic latitudes, because of their propinquity. Galactic star clusters are known to anyone familiar either with the stars or with biblical literature. The most famous group of stars, the Pleiades, is a fairly typical galactic cluster. The number of these clusters catalogued has recently been increased to more than eight hundred. It was a study of them that gave R. J. Trumpler (1) of the Lick Observatory the key to the problem of absorption of light in space in 1930. In a comprehensive study of 334 galactic clusters, Trumpler found that the linear diameters appeared to increase with distance. To explain this observation it was necessary to presume that light was reddened and diminished as it traversed the hundreds or thousands of light years of space between us and the cluster. The obscuring material is strongly concentrated to the plane of the galaxy, but its distribution is not uniform and a blanket correction, such as Trumpler derived, cannot be applied. Rather, the absorption must be determined for each cluster or region under investigation, preferably by accurate photo-electric measures in three wave-lengths, on the UBV system. From the selective absorption, commonly around a few tenths of a magnitude, the total visual absorption may be computed. The ratio of W. Hiltner and H. L. Johnson is 3.0 for visual and 4.0 for photographic absorption. In an extreme case, an example of what absorption can do to a cluster has just

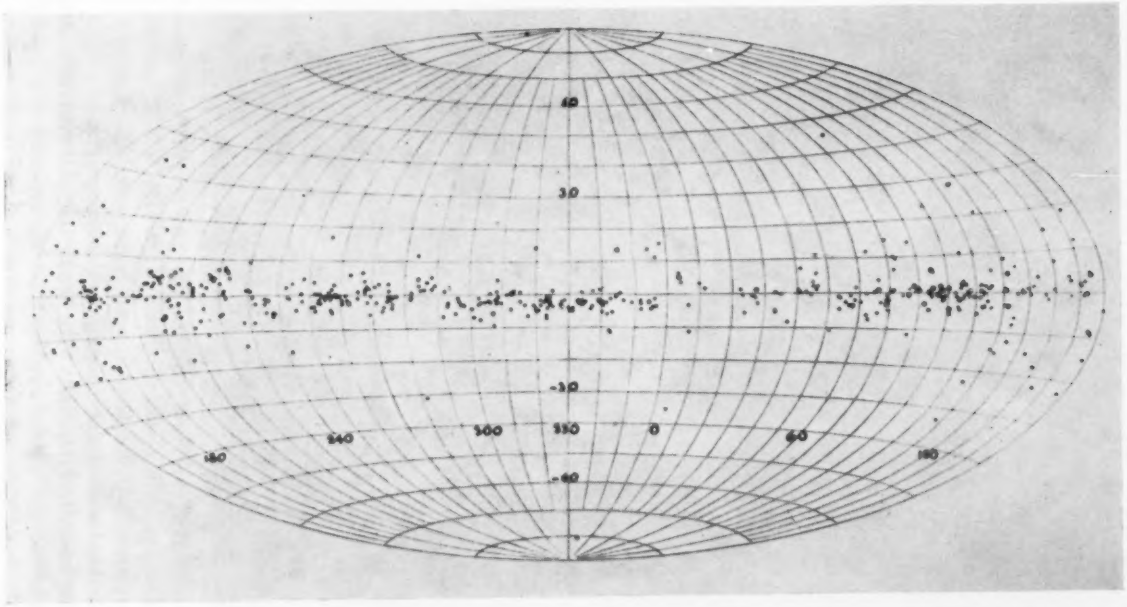

FIGURE 5. Distribution of 514 galactic clusters in galactic co-ordinates on an Aitoff projection. Abscissae are galactic longitudes, ordinates, galactic latitudes.

been reported by Bengt Westerlund (5) for a new cluster in the southern constellation of Ara. This cluster was found with the Schmidt telescope at the Uppsala southern station in Australia. The brightest stars are at V = 14 magnitude, but no stars of the cluster can be seen on plates which reach B = 19. The total visual absorption is 11.2 magnitudes. Apparently in this case the absorbing dust is in the same region of space as the cluster. The correction factor for this degree of absorption would shrink the estimated distance of the cluster from 16,000 light years down to a mere 90! Fortunately this degree of absorption is most unusual, or our astronomical distances would be subject to great uncertainty.

When reliable distances are known, the galactic clusters can be used to trace the outline of the nearest spiral arms of our galaxy. From eighty-two galactic clusters whose distances have all been well determined from three-colour photometry, W. Becker (5) of Basel has just published a map of the three nearest spiral arms. They are outlined by O-B3 clusters and aggregates, as well as H II regions and galactic clusters. These areas include the arm in which our sun is located, known as the Orion arm, the inner spiral arm through Carina and Scutum, and the next outer spiral arm, the Perseus arm. Curiously enough, however, there seems to be no coincidence with the neutral hydrogen regions observed with radio telescopes.

The colour-magnitude diagrams of galactic clusters differ markedly from those of globular clusters, and resemble more strongly the diagram of stars in the sun's neighbourhood. Between different galactic clusters, however, there are substantial differences, which led Trumpler to a classification scheme of galactic clusters based on the colours of the brightest stars. In some, like the Pleiades, they are blue; in others, like the Hyades, yellow or white.

The problem of variable stars in galactic clusters has recently taken an interesting turn. For years, in contrast to globular clusters, it was thought that virtually no variables were in their midst. (It is still true that no RR Lyrae star has been identified as a member of a galactic cluster.) In other words, the kind of variable which predominates in globular clusters is so far absent in galactic clusters. But these latter have their own types of variables. In certain of the young clusters, the RW Aurigae or T Tauri-type variables are found by the dozens or hundreds. These stars, which are particularly numerous in the Orion complex, are in a very early evolutionary state, dwarf variables with absolute visual magnitude +3 or fainter, in which bright hydrogen emission lines appear. Some hundreds of them have been found associated with the nebulous galactic clusters.

Also in the last several years, it has been shown by spectroscopic studies, including radial velocity measures, that certain cepheids are actually members of the clusters near which they are situated—U Sagittarii in Messier 25, S Normae in NGC 6087, and about a dozen others. The presence of these stars with known absolute luminosity is of valuable aid in investigation of both cepheids and galactic clusters.

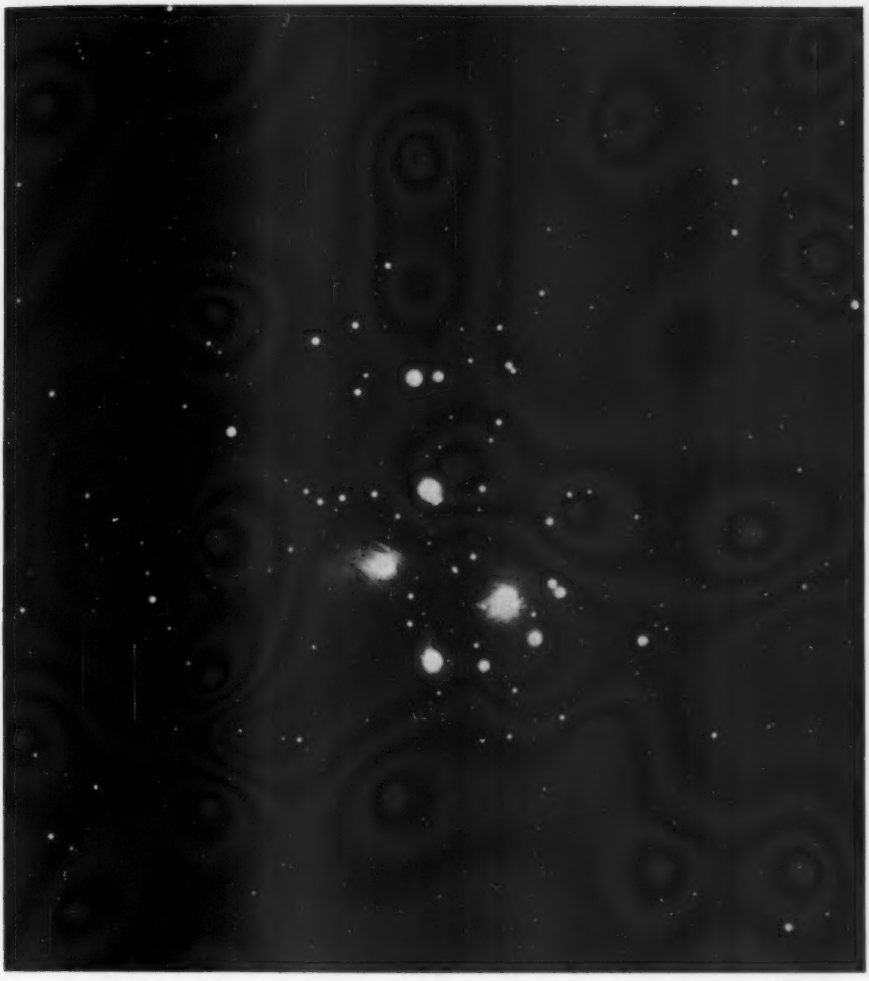

FIGURE 6. The best known galactic cluster, the Pleiades. Lick Observatory photograph, 2^h exposure with Carnegie astrograph by Vasilevskis, Feb. 9, 1951.

A very important problem raised by the stellar content of clusters, whether globular or galactic, is the number of white dwarf stars they contain. Current theory is that the white dwarf stage is a normal one for a star towards the end of its evolution. Quite possibly all stars pass through this stage near the end of their lives. The white dwarf stage comes when the star's main nuclear sources of fuel are exhausted, and the star is shining feebly under the weight of its gravitational contraction. White dwarfs are

presumed to have planetary sizes—some of them no larger than our earth—and stellar masses, so that the density of their material may amount to 10^5 times the density of water. They are composed of degenerate matter. A cubic inch of their centres would weigh forty tons, according to J. L. Greenstein (6).

Sandage (1) predicts, for certain clusters, the numbers of stars which have disappeared from the main sequence because of exhaustion of their energy sources, that is, the white dwarfs. The Hyades should have 23, Praesepe (the Beehive), 20, and Messier 67, a very old galactic cluster, 146. Sandage predicts a staggering number of white dwarfs in a globular cluster like Messier 3—48,500. The catch is that these stars are so faint that even the 200-inch in its present location and with its present auxiliary equipment cannot reach them. Only the Hyades cluster is near enough for thorough investigation, and work is proceeding on it. W. J. Luyten, who, from his proper motion work, has found more white dwarfs than anyone else, doubts the existence of such large numbers in a globular cluster. In fact, he has commented to the writer that the 48,000 white dwarfs in M3 are all safely beyond observational check-up. Recent work by C. B. Stephenson on the Coma cluster and the Ursa Major cluster (7), casts a certain amount of doubt on the presence of white dwarfs in either, while at the same time indicating that the number of white dwarfs among stars in the general field may be higher than is usually supposed.

The colour-magnitude diagram of a cluster, as we have mentioned previously, may be used to determine its age. The assumption is that as protostars form, out of cosmic dust and gas, they contract gravitationally and begin to heat up from the energy thus supplied. When they reach the main sequence, hydrogen burning takes over. The absolute magnitude of the point on the main sequence where the so-called turn-off point comes is an indication of the age of the cluster. At this point, the hydrogen in the outer layers of the star is consumed, the star heats up and becomes a giant. Some of the galactic clusters are very young indeed, even as young as 10^5 or 10^6 years which amounts to hardly a page in the long history of the earth. Proper motion work by K. Aa. Strand (1) has confirmed the young age of the Orion cluster centred on the Trapezium, by giving an expansion age of only 300,000 years for it. M. F. Walker has investigated a number of extremely young clusters, like NGC 2264 which has an age of 3×10^6 years.

On the other hand, the ages computed for the oldest clusters by various investigators such as Crampin and Hoyle (8) and Sandage (9) are now of the order of 10^9 or 10^{10} years. And in recent months the great ages computed for some of the globular clusters have been conflicting with cosmological theory. Sandage of Mount Wilson and Palomar has very recently produced some new data which will have to lead to revision at some point in our scheme of thinking. He has been working on the galactic cluster NGC 188, and the globular clusters Messier 3, 5, and 13. The main sequence termination point occurs for NGC 188 at absolute bolometric magnitude +3.8;

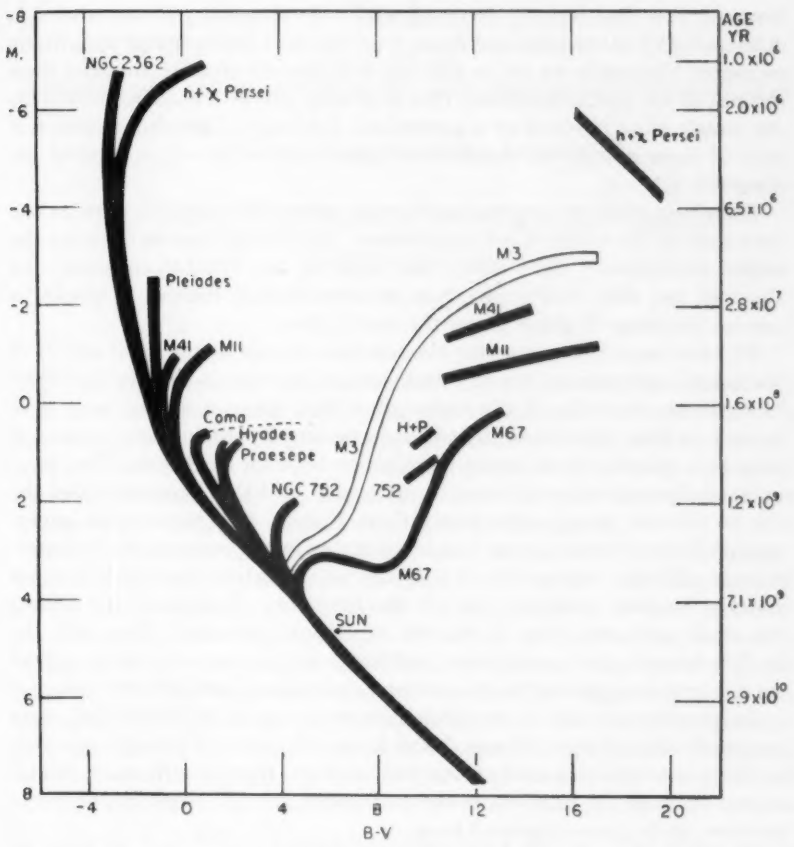

FIGURE 7. Composite colour-magnitude diagram by Sandage for various galactic clusters and the globular cluster Messier 3, Astrophys. J., *125* (1957), 435. The turn-off point from the main sequence is an indication of the age of the cluster. The oldest clusters have the lowest turn-off points.

at +4.15 for M3 and M5, and +3.85 for M13. In all four clusters there is a change in slope of the main sequence caused by the weak Fraunhofer lines, due to low metal abundance. Hoyle's evolutionary tracks have shown that globular cluster stars take longer to evolve to a given configuration. So, though they have the same termination values, the globular cluster Messier 13 is older than the galactic NGC 188. NGC 188 has an age of 16×10^9 years, M13 22×10^9, and M3 and M5 26×10^9 years.

Now these ages are very long compared with the time allowed by model universes on the basis of the beginning of the expansion of galaxies. On a basis of an observed Hubble constant of 75 km/sec per million parsecs of

distance, this time is 7.4×10^9 years, with a deceleration parameter of $+1$, determined by Minkowski and Baum from red shift and apparent magnitude measures. Obviously we are in difficulties if globular clusters are older than the rest of the visible universe. This time scale problem could be solved by the steady state universe or a generalized Eddington-Lemaitre model, but both of these require the deceleration parameter to be -1, instead of the observed $+1$.

Therefore, we have now reached a stage where the available data on the time scale of the universe are inconsistent. Something is amiss in either the stellar evolutionary time scale, the value of the Hubble constant, the observed red shift–magnitude data, or cosmological theory. It would be rash at this stage to guess where the trouble lies.

We have seen, then, that star clusters have shown us the great extent of our galaxy, and pointed the way to the massive centre in Sagittarius. They have shown the error of the assumption that space is empty, and have warned us that light from distant objects may be diminished in amount through a celestial fog of spotty distribution before it reaches us. They have outlined the nearest spiral arms of our galaxy, and they have provided the clue to old and young stellar populations. Finally, they have raised important problems for the future. Just what status in our universe do the intergalactic globular clusters have? Are they an indication that there is other material between galaxies? What is the frequency of white dwarfs among the stars, and are there thousands in globular clusters? How will the conflict between the ages determined for globular clusters and the age of the universe be resolved? Is the universe older than 7,400,000,000 years, or is the evolutionary time scale which leads to an age of 26,000,000,000 years for the globular clusters Messier 3 and Messier 5 in error? Though man may be flying into space to explore our solar system, there is still much fundamental study of the heavens, of the nature and age and origin of our entire universe, to be done at ground level.

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SECTION III

HENRY MARSHALL TORY ADDRESS

The Scorpio-Centaurus Cluster and the Galactic Distance Scale

R. M. PETRIE, F.R.S.C.

THE very luminous and hot stars of spectral class B are extensively used in spectroscopic investigations of the galaxy. They are located in the central plane of the galaxy, are associated with interstellar material, and are members of clusters and associations which delineate the spiral structure. Because they are intrinsically very bright we can observe them at the larger distances necessary for galactic exploration.

We must, of course, know the distances to the stars used in our investigations if we are to study the size of the galaxy, its structure, and its dynamical properties. These stars are far beyond the reach of direct distance measurements and we are forced to locate them by an indirect method known as the method of spectroscopic parallaxes. In essence, this means that we estimate the true brightness of a star (its absolute magnitude) from the appearance of its spectrum and, by comparison with its observed brightness, infer its distance from us. For example, the bright star γ Orionis (Bellatrix) is found spectroscopically to have a true brightness of 480 times that of the sun. We observe it to be 0.38×10^{-11} of the sun's brightness and therefore it must be $\left(\frac{480}{.38 \times 10^{-11}}\right)^{\frac{1}{2}}$ times the distance of the sun. This turns out to be 11,300,000 ast. units, or 180 light years.

It is not hard to find spectroscopic clues to the absolute magnitude of a B-type star but it is extremely difficult to assign reliable numerical values to a calibration of the absolute magnitude effects. This is because all B stars, generally speaking, are too remote for us to make direct measures of their distances and true brightnesses and we must, therefore, resort to indirect methods.

Several spectroscopic systems of absolute magnitude have been devised. Here we shall compare and discuss the MK system developed by Morgan and his associates at the Yerkes Observatory and the Victoria system developed by Petrie. The former system has already been applied extensively to the study of galactic structure and star clusters and associations and the latter will be used in the analysis of a large volume of radial-velocity data only recently obtained. The MK system assigns stars to one of six luminosity

classes by means of visual examination of low-dispersion spectrograms: the Victoria system depends upon the measured intensity of the hydrogen absorption in the stellar spectrum. The calibration of the luminosity classes was made through absolute magnitudes determined from mean parallaxes and from a comparison of colour-magnitude sequences in galactic clusters with such sequences among nearby stars. The calibration of the hydrogen absorption strength was made from differential magnitudes in galactic clusters and visual-binary systems and from "moving-cluster" distances. The Victoria system has been tested by the mean parallaxes of the nearer B stars and by comparison with absolute magnitudes of eclipsing binaries. The tests confirm the Victoria absolute magnitudes although the confirmation cannot, of necessity, be a strong one.

The MK absolute magnitudes are systematically brighter than the Victoria values. At one time the difference appeared to be 0.7 mag. but a recent revision of the zero point of the MK system has reduced this. The MK system now is fixed by absolute magnitudes derived from distances of stars composing the well-known Scorpio–Centaurus moving cluster, according to a recent analysis of the motions by Bertiau. Sixteen of the stars have absolute magnitudes assigned from measures of hydrogen absorption and it is possible, therefore, to make a direct comparison of the two systems. The mean difference is

$$\text{MK}-\text{DAO} = -0.41 \text{ mag.} \pm .10.$$

This corresponds to a scale of galactic distances some 20 per cent greater for the MK system than for the Victoria system and the discrepancy should be removed if possible. The rest of this discussion is concerned with the question of deducing the absolute magnitudes of stars belonging to the Scorpio–Centaurus group.

A group of stars possessing common motion is called a moving cluster. Several moving clusters are known to astronomers, the common space motion of the member stars being recognized by: (*a*) an apparent convergence, or divergence, of the angular motions (proper motions) in the tangent plane to the celestial sphere, the point of intersection of the proper motions produced being called the convergent; and, (*b*) a relation between the radial velocities and the angular distances of the stars from the convergent.

The *directions* of the observed proper motions allow us to find the convergent point and observations of the line-of-sight velocity of one or more member stars give us the space motion of the cluster. The *sizes* of the proper motions then yield the distances of individual stars of the cluster, from which we may calculate their true brightnesses or absolute magnitudes. These absolute magnitudes in turn are used to calibrate the spectroscopic system from which the distance to any star may be derived.

The method described above is exact for a true moving cluster and, within the limits of observational error, will give precise distances and

absolute magnitudes of the member stars. Thus, if the stars of the Scorpio–Centaurus group form a true moving cluster, the distances and absolute magnitudes derived by Bertiau are correct and the Victoria absolute magnitude system is wrong. Because of the importance of this point a new study has been made of the kinematical nature of the group.

Bertiau employed proper motions and radial velocities of seventy-seven stars considered to be members of a moving cluster. In our study Bertiau's proper motions were adopted but the radial velocities were improved by the incorporation of new observations made at Mt. Stromlo and only recently published. Also, sixteen additional stars were considered as qualifying for membership in the group and their motions were included. The new computations agree well enough with Bertiau's in fixing the convergent point but give important differences in the derived space motion of the cluster. The absolute magnitude systems calculated for the cluster stars would from this cause alone show a range of 0.6 mag. among different solutions. This sensitivity to different possible solutions is a serious matter and should be carefully considered before adopting the group as a source of an absolute magnitude calibration.

The convergent of the Scorpio–Centaurus stars is found to lie quite close to the apex of solar motion. One may enquire, therefore, whether the apparent convergence of the proper motions is caused by the solar motion alone without there being any common space motion among the stars of the group. To test this hypothesis we remove standard solar motion from the proper motions. When this is done the stars no longer appear to share a common motion but look rather as if their tangential motions were at random. This result is shown in Figure 1 where the upper plot shows the observed proper motions of the individual stars and the lower shows the residual proper motions after the removal of the effects of the sun's motion. The residual motions average close to zero and are of the size of observational errors in proper motion determinations. Thus there is no convincing evidence, from the proper motions, of the existence of common motion of the stars of the Scorpio–Centaurus group.

The radial motions show a rather large velocity of recession which does not vanish with the removal of solar motion. A plot of the motions in the plane of the galaxy shows a definite trend away from the sun and towards the galactic centre. There is, however, a rather large spread even in the radial component. The mean value is $+7.2\pm0.5$ km/sec. but the average residual velocity about the mean is 4.3 km/sec. One must conclude that the radial motions indicate a general drift towards the galactic centre but they exhibit a scatter too great to support the hypothesis of common motion. It should be added that the radial-velocity information is not very reliable. It is very likely that a fairly large fraction of the stars vary in radial velocity. The values adopted are often the means of three or four observations and there is little chance that the systemic velocity has been

obtained. Incidentally, if a number of undetected binary stars is present, the deduced absolute magnitudes of those particular stars will be in error, being too bright.

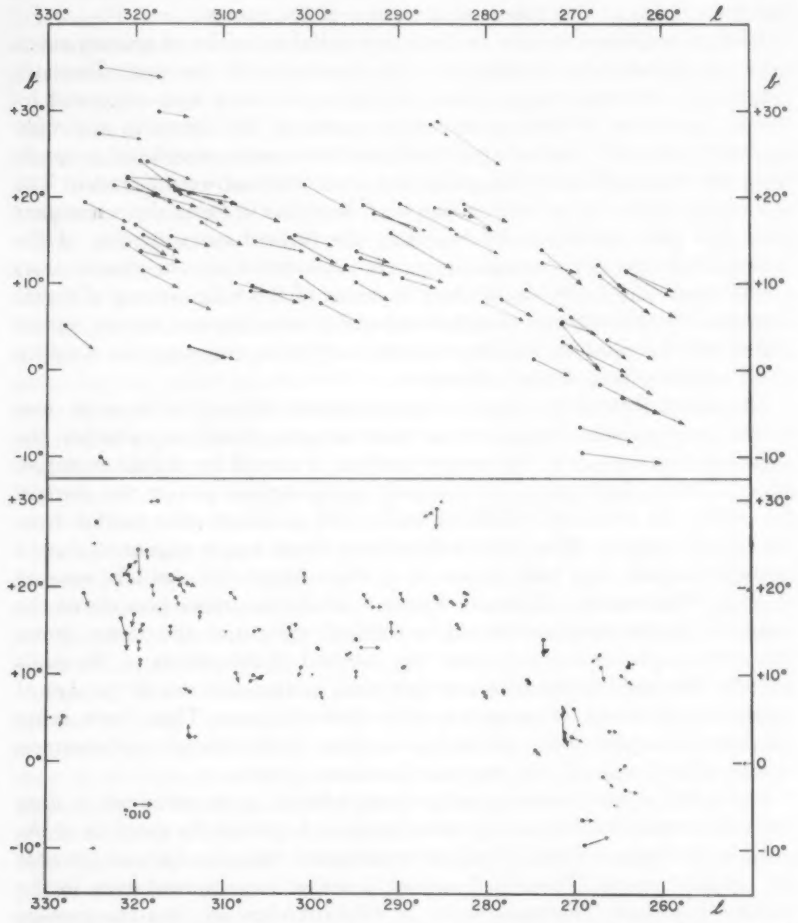

FIGURE 1. Proper motions of stars of the Scorpio–Centaurus group. Upper plot, observed motions; lower, the residual motions after solar motion removed.

There is, then, a reasonable doubt that the Scorpio–Centaurus group forms a true moving cluster. If it does not we cannot apply the conventional analysis to obtain distances and absolute magnitudes of individual stars. We may, however, calculate a reliable mean distance from the large and

well-determined proper motions on the assumption that they are a result of solar motion combined with the usual random stellar motions. This has been done for the sixteen stars whose absolute magnitudes have been measured spectroscopically at Victoria. The comparison confirms the Victoria system and suggests a correction of +0.4 mag. to the MK absolute magnitudes of B stars.

It is concluded that the Scorpio–Centaurus group does not fulfil the requirements which would classify it unequivocally as a true moving cluster, and the various uncertainties in its kinematical properties make it unfit as the origin of a system of absolute magnitudes. It is also concluded that the MK system of assigning absolute magnitudes is not necessarily to be preferred over that adopted at Victoria.

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